(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 278 070 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 87116865.4

(51) Int. Cl.4: H01Q 9/04 , H01Q 1/32

(22) Date of filing: 16.11.87

(30) Priority: 23.12.86 US 945613

(43) Date of publication of application: 17.08.88 Bulletin 88/33

(84) Designated Contracting States: AT BE CH DE ES FR GB GR IT LI LU NL SE

(71) Applicant: BALL CORPORATION
345 South High Street
Muncie Indiana 47302(US)

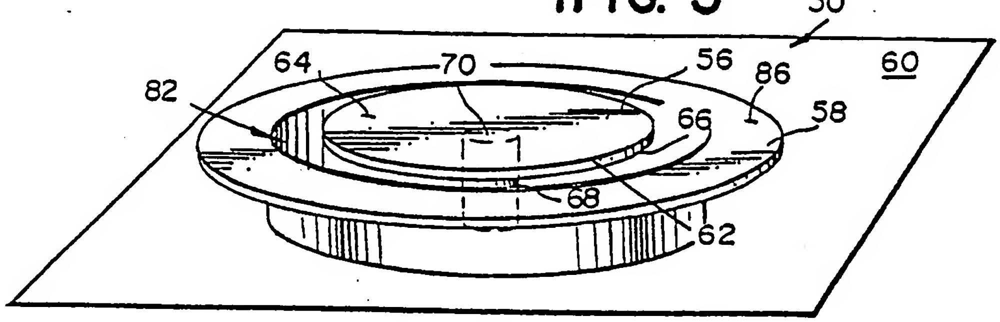
(72) Inventor: Johnson, Russell Wayne
6137 Olde Stage Road
Boulder Colorado 80302(US)
Inventor: Munson, Robert Eugene
7355 Valmont Road
Boulder Colorado 80301(US)

(74) Representative: UEXKÜLL & STOLBERG
Patentanwälte
Beselerstrasse 4
D-2000 Hamburg 52(DE)

(54) **Circular microstrip vehicular rf antenna.**

(57) A compact, easy to manufacture quarter-wavelength microstrip element especially suited for use as a mobile radio antenna has performance which is equal to or better than conventional quarter wavelength whip-typ mobile radio antennas. The antenna is not visible to a passerby observer when installed, since it is literally part of the vehicle. The microstrip radiating element is conformal to a passenger vehicle, and may, for example, be mounted under a plastic roof between the roof and the headliner.

FIG. 3



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CIRCULAR MICROSTRIP VEHICULAR RF ANTENNA

SPECIFICATION

This application is related to copending commonly-assigned application Serial No. 946,788 of Johnson et al, filed December 29, 1986 entitled "NEAR-ISOTROPIC LOW-PROFILE MICROSTRIP RADIATOR ESPECIALLY SUITED FOR USE AS A MOBILE VEHICLE ANTENNA" (Docket No. 63-46, D-1284), the disclosure of which is incorporated by reference herein.

This invention generally relates to radio-frequency antenna structures and, more particularly, to low-profile resonant microstrip antenna radiators.

Microstrip antennas of many types are well known in the art. Briefly, microstrip antenna radiators comprise resonantly dimensioned conductive surfaces disposed less than about 1/10th of a wave length above a more extensive underlying conductive ground plane. The radiator element may be spaced above the ground plane by an intermediate dielectric layer or by a suitable mechanical standoff post or the lik . In some forms (especially at higher frequencies), microstrip radiators and interconnecting microstrip RF feedline structures are formed by photochemical etching techniques (like those used to form printed circuits) on one side of a doubly clad dielectric sheet, with the other side of the sheet providing at least part of the underlying ground plane or conductive reference surface.

Microstrip radiators of various types have become quite popular due to several desirable electrical and mechanical characteristics. The following listed references are generally relevant in disclosing microstrip radiating structures:

Inventor	Patent No.	Issued
Murphy et al	4,051,477	Sep. 27, 1977
Taga	4,538,153	Aug. 27, 1985
Campi et al	4,521,781	Jun. 4, 1985
Munson	3,710,338	Jan. 9, 1973
Sugita	Jap. 57-63904	Apr. 17, 1982
Jones	3,739,386	Jun. 12, 1973
Firman	3,714,659	Jan. 30, 1973
Farrar et al	4,379,296	Apr. 5, 1983

Although microstrip antenna structures have found wide use in military and industrial applications, the use of microstrip antennas in consumer applications has been far more limited despite the fact that a great many consumers use high frequency radio communications every day. For example, cellular car radio telephones, which are becoming more and more popular and pervasive, could benefit from a low-profil microstrip antenna radiating element if such an element could be conveniently mounted on or in a motor vehicle in a manner which protects the element from the environment and if such an element could provide sufficient bandwidth and omni-directivity once installed.

The following list of patents are generally relevant in disclosing automobile antenna structures:

Inventor	Patent No.	Issued
Moody	4,080,603	Mar. 21, 1978
Affronti	4,184,160	Jan. 15, 1980
DuBois et al	3,623,108	Nov. 23, 1971
Zakharov et al	3,939,423	Feb. 17, 1976
Chardin	UK 1,457,173	Dec. 1, 1976
Boyer	2,996,713	Aug. 15, 1961
Allen, Jr., et al	4,317,121	Feb. 23, 1982
Gabler	2,351,947	June 20, 1944
Okumura	3,611,388	October 5, 1971

Mobile radio communications presently relies on conventional whip-type antennas mounted to the roof, hood, or trunk of a motor vehicle. This type of conventional whip antenna is shown in prior art Figure 1. A conventional whip antenna typically includes a half-wavelength vertically-oriented radiating element 12 connected by a loading coil 14 to a quarter-wavelength vertically-oriented radiating element 16. The quarter-wavelength element 16 is mechanically mounted to a part of the vehicle.

Although this type of whip antenna generally provides acceptable mobile communications performance, it has a number of disadvantages. For example, a whip antenna must be mounted on an exterior surface of the vehicle, so that the antenna is unprotected from the weather (and may be damaged by car washes unless temporarily removed). Also, the presence of a whip antenna on the exterior of a car is a good clue to thieves that an expensive radio telephone transceiver probably is installed within the car.

The Moody and Affronti patents listed above disclose externally-mounted vehicle antennas which have some or all of the disadvantages of the whip-type antenna.

The DuBois and Zakharov et al patents disclose antenna structures which are mounted in or near motor vehicle windshields within the vehicle passenger compartment. While these antennas are not as conspicuous as externally-mounted whip antennas, the significant metallic structures surrounding them may degrad their radiation patterns.

The Chardin British patent specification discloses a portable antenna structure comprising two opposed, spaced apart, electrically conductive surfaces connected together by a lump-impedance resonant circuit. One of the sheets taught by the Chardin specification is a metal plate integral to the metal chassis of a radio transceiving apparatus, while the other sheet is a metal plate (or a piece of copper-clad laminate of the type used for printed circuit boards) which is spaced away from the first sheet.

The Boyer patent discloses a radio wave-guide antenna including a circular flat metallic sheet uniformly spaced above a metallic vehicle roof and fed through a capacitor.

Gabler and Allen Jr., et al disclose high frequency antenna structures mounted integrally with non-metallic vehicle roof structures.

Okumura et al teaches a broadcast band radio antenna mounted integrally within the trunk lid of a car.

It would be highly desirable to provide a low profile microstrip-style radiating element which has a relatively large bandwidth, can be inexpensively produced in high volumes, can be installed integrally within or inside a structure found in most passenger vehicles, and which provides a nearly isotropic vertical directivity pattern.

SUMMARY OF THE INVENTION

The present invention provides a circularly shaped conductive radiator element of at least one-half wavelength in diameter spaced above a conductive reference surface by substantially less than one-fourth wavelength. The circularly shaped radiator element is electrically shorted to the reference surface near the center of the element to form a shorted one-fourth wavelength radius annular cavity having a circular radiating slot at its outer edge. An RF signal feed connection connected between the reference surface and a predetermined matched impedance point on the circular radiator element couples RF energy to/from the antenna structure.

A further annular conductive radiator element(s) may disposed above th r ference surface by

substantially less than one-fourth wavelength and spaced radially outwardly from the circular radiating slot formed by th circular radiator element. This further radiator element(s) also have resonant radial dimensions to form further circular radiating slots at their edges.

The antenna structure provided by the present invention has relatively broadband characteristics (e.g., less than 2.0:1 VSWR over a frequ ncy range of over 820 MHz - 890 MHz), is vertically polarized, and is substantially omni-directional. The antenna structure of the invention is therefore ideal for installation in an automobile of the type having a passenger compartment roof including a rigid, outer non-conductive shell and an inner headliner layer spaced apart from the outer shell to define a cavity therebetween. The antenna structure may be disposed within that cavity, preferably with the radiator element and/or passive element mechanically mounted to an inside surface of the outer shell.

The antenna structure of the invention may be inexpensively mass-produced using die stamping techniques. A discoid piece of metal may be die stamped to draw a cylindrical protruding portion from its center. A larger discoid piece of metal may be die stamped to provide a cylindrical cup-shaped portion having a circular flat bottom, a cylindrical side wall, and an annular outwardly extending flange portion extending from the upper edge of the side wall. The part with the cylindrical protruding portion is disposed within the cup-shaped portion of the other part, and the protruding portion is attached to the bottom of the cup-shaped portion (e.g., by inserting tabs extending from the protruding portion into corresponding slots in the circular bottom). The process of manufacture described above may be used to mass produce the antenna structure of the present invention at very low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention may be better and more completely understood by referring to the following detailed description of preferred embodiments in conjunction with appended sheets of drawings, of which

FIGURE 1 is a schematic side view of a prior art whip-type quarter-wavelength mobile antenna radiator;

FIGURE 2 is a schematic view of a passenger vehicle and roof structure;

FIGURE 3 is a side view in perspective of a presently preferred exemplary embodiment of th antenna structure provided by the present invention, this embodiment including a circular radiator element and a single annular parasitic element;

FIGURE 4 is a side view in cross-section of the embodiment shown in FIGURE 3;

FIGURE 4A is a top view in plan of the circular radiator element shown in FIGURE 3 schematically illustrating the resonantly-dimensioned annular resonant cavity defined between that radiator element and a reference surface;

FIGURE 5 is a side view in cross-section of a further embodiment of the antenna structure of the present invention installed in the automobile roof structure shown in FIGURE 2, this embodiment also having a circular radiator element and a single annular parasitic element;

FIGURE 6 is an exploded view in perspective of two die stamped parts which, when assembled together, form the antenna structure shown in FIGURE 5;

FIGURE 7 is a side view in cross-section of a still further embodiment of the present invention having a circular radiator element and three annular parasitic elements;

FIGURE 8 is a top view in plan of the embodiment shown in FIGURE 7;

FIGURE 9 is a top view in plan of a further embodiment of the antenna structure of the present invention, this embodiment having a circular radiator element and no parasitic elements and including a capacitive microstrip line stub resonant impedance matching network for obtaining a broadband impedance match;

FIGURE 10 is a side view in cross-section of the embodiment shown in FIGURE 5 incorporating th capacitive stub impedance matching network of FIGURE 9;

FIGURE 11 is a side perspective schematic view of the radiation pattern of the antenna structure of the present invention;

FIGURE 12 is a side schematic view of the radiation pattern of the embodiment shown in FIGURE 3;

FIGURE 13 is a Smith chart showing actual field strength measurements of the vertically polarized radiation pattern of the antenna structure shown in FIGURE 7 as installed in a passenger vehicle and also showing the radiation pattern of the prior art whip antenna shown in FIGURE 1;

FIGURE 14 is a Smith chart of input impedance of an antenna structure of the present invention measured over a frequency range of 820 MHz - 890 MHz; and

FIGURE 15 is a side view in perspective of a further embodiment of the present invention having a circular reference surface which is coextensive with the circular radiator element.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIGURE 3 is a side perspective view of a presently preferred exemplary embodiment of a vehicle-installed ultra high frequency (UHF) radio frequency antenna structure 50 in accordance with the present invention.

Antenna structure 50 is installed within a roof structure 52 of a passenger automobile 54 (or other vehicle) in the preferred embodiment (see FIGURE 2). Antenna structure 50 is of a "low profile" design so that it may actually be integrally incorporated into roof structure 52.

The embodiment of antenna structure 50 shown in FIGURE 3 includes three elements a circular conductive radiator element 56; an annular parasitic element 58; and a conductive reference surface ("ground plane") 60. The structure of element 56 of the preferred embodiment will now be discussed.

As can best be seen in FIGURES 3 and 4 together, circular radiator element 56 includes a substantially flat disk 62 of conductive material (e.g., aluminum or copper). Disk 62 has a flat, circular upper surface 64 and a flat circular lower surface 66. A cylindrical post 68 (which may be hollow if desired) mad of conductive material is electrically connected (e.g., by a conductive fastener passing through disk 62, post 68 and reference surface 60) to disk lower surface 66 at substantially the center of disk 62 and is also conductively bonded to reference surface 60. Post 68 spaces disk 62 above reference surface 60, and also defines an annular resonant cavity, as will now be explained.

The diameter of disk 62 and the diameter of cylindrical post 68 are chosen based upon the desired RF operating frequency range of antenna structure 50 such that a shorted quarter wavelength radius annular resonant cavity is defined between disk lower surface 66 and reference surface 60 (the reference can be a flat sheet of copper 10 inches by 16 inches if desired). Thus, a cross-sectional volume 72 bounded by reference surface 60, cylindrical post outer wall 76, disk lower surface 66, and an imaginary line 78 drawn normal to disk lower surface 66 and reference surface 60 between disk outer periphery 80 and the reference surface forms a quarter wavelength (/4) resonant cavity. The same is true along each and every radius of disk 62 due to the symmetry of the disk and cylindrical post 68 (see FIGURE 4A). Thus, the volume between disk lower surface 66 and reference surface 60 may be considered a shorted one-fourth wavelength radius annular cavity 82. A circular radiating slot 84 is formed along the gap between disk outer periphery 80 and conductive reference surface 60.

In the preferred embodiment, post 68 has a diameter of approximately 1.125 inches and a height of approximately 0.6 inches to 0.75 inches; and disk 62 has a diameter of approximately 4.125 inches (which is slightly greater than one-half wavelength) for a desired center operating frequency of about 857 MHz.

Disk 62, post 68 and conductive reference surface 60 can be used without any additional structure as a UHF RF antenna with many advantages. Because of the symmetry of this combination of elements, th resulting antenna has a substantially omni-directional vertically polarized radiation pattern. The structure also has relatively broadband characteristics due to its circularly symmetric configuration, and may be fed directly by a coaxial RF transmission line if desired (e.g., by simply connecting the coax center conductor or associated standard coaxial connector center pin to an experimentally-determined point on disk lower surface 66 somewhere between post 68 and disk outer periphery 80 which yields an optimum impedance match).

It has been found that the antenna structure bandwidth increases as the height of post 68 (and thus, the spacing between disk lower surface 66 and reference surface 60) is increased. However, the spacing between disk lower surface 66 and reference surface 60 should preferably remain substantially less than a quarter wavelength if the antenna directivity and other performance characteristics described her in are desired (since the antenna would have the characteristics of a quarter wavelength top-loaded vertical monopole rather than those of a circular radiating slot if the electrical height of post 68 were on the ord r of a quarter wavelength).

It may be desirable (e.g., in certain mobile radio applications) to reduce the angle of radiation of antenna structure 50 in order to increase the effective gain of the antenna structure along radiation paths approximately within the plane of disk 62. For example, most land targets which an operator within automobile 54 desires to communicate with (e.g., other mobile radio transceiver antennas, base station antennas, etc.) will probably be located approximately within the plane of disk 62 (that is, somewhere along the horizon if the disk is oriented parallel to the surface of the earth). It may therefore be desirable to increase the amplitude of the radiation lobes toward the horizon and increase the area covered by the null

directly above disk 62 (see, for example, FIGURE 13).

The gain of antenna structure 50 toward the horizon can be increased and the angle of radiation of the antenna structure can be lowered by providing one or more annular "director" parasitic elements 58 to direct radiated energy towards the horizon. A discussion of the structur and operation of such parasitic elements will now be presented.

The embodiment shown in FIGURES 3 and 4 includes a single parasitic element 58. Parasitic element 58 includes a circular flat ring ("annulus") 86 spaced above conductor reference surface 60 and preferably lying within the plane of disk 62. As can best be seen in FIGURE 4, ring 86 has a free circular periphery edge 88 and a further edge 90. Edge 90 is electrically shorted to reference surface 60 by shorting portion 92 (shorting portion also is used in the preferred embodiment to support ring 86 above reference surface 60). Ring 86 is concentric with disk 62 --that is, the center point of the circle defined by the ring and the center point of disk 62 are the same.

Ring 86 is preferably parallel to reference surface 60 (as is disk 62). The width of ring 86 (i.e., the distance between ring peripheral edge 88 and shorting portion 92) is selected based upon desired operating frequency so that an annular quarter wavelength resonant cavity 94 is formed, this cavity being bounded by a ring lower surface 96, a shorted portion inner surface 98, conductive reference surface 60, and an imaginary line 100 normal to both reference surface 60 and the plane of ring 86 and drawn between ring peripheral edge 88 and the reference surface. Resonant cavity 94 opens in a circular radiating slot 102 concentric with radiating slot 84.

In the preferred embodiment, the spacing between ring lower surface 96 and conductive 60 is approximately 0.6 inches to 0.75 inches (the same spacing as that between disk lower surface 66 and the reference surface); and the distance between shorting portion inner surface 98 and peripheral edge 88 is approximately 1.5 inches for a center operating frequency of 857 MHz.

As will be explained, circular radiator element 56 is driven (i.e., connected to an RF transmission line), and passive element 58 is parasitically coupled to element 56 (i.e., there is no direct connection between the transmission line and the parasitic element). Radiating slot 102 is a parasitic circular radiating slot concentric with the radiating slot 84 defined by driven element 56. The effect of parasitically-coupled radiating slot 102 is to decrease the angle of radiation of antenna structure 50 by directing more of the radiation emitted by radiator element 56 toward the horizon (and likewise, directing more of the radiation received from the horizon towards slot 84 when the antenna structure is used for receiving signals). Radiating slot 102 thus increases antenna gain at the horizon when radiator element 56 and ring 86 are horizontally disposed.

The spacing between slot 84 and slot 102 is critical to the radiation characteristics of antenna structure 50. An analogy may be drawn to the so called "Yagi" or "Yagi-Uda" antenna array, which includes self-resonant parasitic linear dipole-type elements spaced at 0.2 wavelength intervals. Discussions of such Yagi arrays may be found in a variety of publications including, for example, <u>The ARRL Antenna Book</u> (American Radio Relay League) beginning at page 145. The relationship between parasitic radiating slot 102 and radiating slot 104 is analogous to the relationship between a self resonant director dipole parasitic element of a Yagi array and a driven dipole element of that array.

In the preferred embodiment of the present invention, the distance between parasitic radiating slot 102 and radiating slot 84 is nominally 0.2 wavelengths (2.75 inches for a center operating frequency of 857 MHz), although the actual spacing is preferably optimized through experimentation to obtain desired antenna performance characteristics and to ensure resonance (since the coupling between elements 56 and 58 may have an effect on the resonant frequencies of both of cavities 82 and 94).

The embodiment of antenna structure 50 shown in FIGURE 3 may be fabricated by making disk 62, post 68, parasitic element 58 and conductive reference surface 60 individually from copper or other conductive material (using, for example, conventional metal cutting and machining processes) and then assembling the antenna structure using conventional fasteners (e.g., sheet metal screws and/or nuts and bolts). Prototypes of the invention have been made using such techniques. However, if antenna structure 50 is to be mass-produced for incorporation into hundreds of thousands (or millions) of passenger vehicles, it is desirable to use a fabrication process which is less costly and time consuming.

FIGURE 5 is a side view in cross-section of another embodiment of antenna structure 50 having a circular radiator element 56 and a parasitic director element 58. The embodiment shown in FIGURE 5 is integrally incorporated into vehicle roof structure 52, and is fabricated from two die-stamped parts 104 and 106 using fabrication processes which can readily yield high volumes of parts at very low cost.

Conventional automobile roof structure 52 of passenger automobile 54 includes an outer rigid non-conductive (e.g., plastic) shell 108 and an inner "headliner" layer 110 spaced apart from the outer shell to form a cavity 112 having a height of approximately one inch therebetween. Headliner 110 is typically made

of cardboard or other inexpensive, thermally insulative material. A layer of foam or cloth (not shown) may be disposed on the headliner surface 114 bounding the passenger compartm nt of automobile 54 for aesthetic and other reasons. Headliner 110 is a structure typically thought of as the inside "roof" of the automobile passenger compartment (and on which the dome light is typically mounted). The outer shell 108 is self-supporting, and is rigid and strong nough to provide good protection against the weather.

The embodiment of antenna structure 50 shown in FIGURE 5 is made of two parts: part 104 and part 106. Part 106 forms disk 62 and post 68, while part 104 forms ring 86, shorting portion 92 and conductive reference surface 60 (in conjunction with a layer of aluminum foil or other thin conductive layer which is electrically connected to the automobile chassis and acts as both a ground plane and as a shield to protect passengers within the vehicle from being exposed to microwaves).

Referring to FIGURE 6, part 106 is fabricated by stamping a disk made of conductive metal (aluminum is preferred because of its low cost, light weight and ductility, although copper might be used instead) using a conventional die-stamping machine and die. The disk from which part 106 is stamped has a diameter which is preferably slightly larger than the desired diameter of disk 62, and has a thickness which is great enough to permit a projecting portion of a desired length (post 68) to be drawn from the disk center.

The disk from which part 106 is made is clamped about its periphery using a resilient clamp, and a rod-like stamping tool is then lowered into the center of the disk with sufficient force to draw the metal from th center of the disk downward (e.g., into a cylindrical bore positioned under the disk and aligned with the rod). Such conventional die stamping techniques are well known to those skilled in the art, and need not be discussed in detail herein (likewise, a variety of different die stamping techniques different from the technique just described might well be used to fabricate part 106).

The disk from which part 106 is made is stamped so that a projecting portion 118 is formed at the center of the disk and extends (downwardly in the orientation shown in FIGURE 6) from disk lower surfac 66. Projecting portion 118 is frustoconical at the point it joins with disk lower surface 66, and is cylindrical at its distal terminus 119. The resulting conical depression 120 in the center of disk upper surface 64 does not significantly degrade the performance of radiating element 56. Likewise, although post 68 is ideally cylindrical along its entire length so that annular cavity 72 has a quarter-wavelength dimension near reference surface 60 as well as near disk lower surface 66, the frustoconical, tapered shape of the post will not significantly degrade the resonant properties of annular cavity 84. As part of the same stamping step (or possibly, through an additional machining or stamping process occurring after the first stamping), "ears" or tabs 122 are formed which extend from distal terminus 119 of projecting portion 118 as shown.

To fabricate part 104, a larger circular disk (also of aluminum or copper) is stamped using a cylindrical die to form a cylindrical cup-shaped portion having a cylindrical side wall 122 and a circular bottom 126 (such techniques are commonly used to form cakepans and other similar articles). Subsquently to the stamping step, a conventional flanger is used to bend the upper edge of cup-shaped portion side wall 122 into an outwardly extending flange portion 124 (depending upon the type of flanger used, one or plural separate steps may be required to form an annular flange which meets cylindrical side wall 122 at a right angle).

Finished part 104 has a substantially flat, circular bottom 126 which closes the bottom edge 127 of cup-shaped portion 128. Flange 124 extends outwardly from the open edge of cylindrical portion 128, and preferably lies in a plane which is parallel to the plane containing bottom 126. Holes 130 corresponding to tabs 122 are preferably cut into bottom portion 126.

Parts 104, 106 are then assembled by inserting tabs 122 into holes 130 and bending the tabs ov r (or using some type of metal bonding/fastening technique such as soldering or brazing) so that protruding portion 118 (i.e., post 68) is approximately normal to bottom 126 and flange 124 (i.e., ring 86) is concentric with disk 62.

The resulting assembled structure is installed into vehicle roof structure 52 (see FIGURE 5) by electrically coupling the lower conductive surface of bottom 126 to aluminum foil layer 116 (using conductive foil tape, by inserting the cup-shaped portion into a retaining ring (not shown) electrically and mechanically connected to the foil, or by some other cost-effective technique) and also by mechanically attaching disk 62 and/or flange 124 to outer shell 108 (using, for example, plastic pins 134).

A coaxial RF feedline 136 may be directly connected to a predetermined impedance matching point 138 on disk 62 (the position of this point can be determined experimentally on prototypes and a hole 140 for establishing the connection can be cut through disk 62 during mass-production). Coaxial cable 136 can pass through a hole 142 cut through cylindrical wall 122. Diameters and thickness s of the disks from which parts 104 and 106 are made (and, of course, the dim nsions of the dies used in the stamping process) are carefully chosen so that the critical dimensions discussed in FIGURES 3 and 4 are present in the final fabricated structure.

As described previously, a single passive element 58 provides an appreciable reduction in angle of radiation of antenna structure 50. Additional concentric shorted rings 86 may be used to provide still lower angles of radiation (and thus, still further increase effective gain toward the horizon). FIGURES 7 and 8 show a further embodiment of antenna structure 50 including circular radiator element 56, annular passive element 58, a second annular passive element 142, and a third, outer passive element 170. Passive elements 142 and 170 have substantially the same structure as that of passive element 58 described previously, although they both have larger diameters than that of parasitic element ring 86 (since th y are spaced radially outwardly from that ring).

Passive element 142 is concentric with elements 58 and 56 and includes a ring 144 which is coplanar with ring 86 and disk 62. The passive radiating slot 146 and associated quarter wavelength resonant cavity 148 defined by passive element 142 is parasitically coupled to slots 84 and 102, and acts as a furth r director of radiation.

Passive element 170 is concentric with elements 58, 56 and 142, and includes a ring 172 which is coplanar with rings 86 and 144 and with disk 62. The passive radiating slot 174 and associated quarter wavelength resonant cavity 176 defined by passive element 142 is parasitically coupled to slots 84, 102 and 146, and acts as a still further director of radiation.

The spacings between slots 102, 146 and 174 may niminally follow the 0.2 wavelength Yagi array spacing discussed previously, although actual spacings should be optimized through experimentation.

Further reduction of radiating angle can be achieved by providing still further concentric passive elements. The structure shown in FIGURES 7 and 8 (with three annular parasitic elements and circular radiating element 56) has been constructed and tested, and exhibited a relatively low angle of radiation (and thus, additional gain toward the horizon) and relatively broadband characteristics. Depending upon the application, however, the expense of providing more than two or three passive annular elements may not justify the further incremental improvement in antenna performance (indeed, in some applications, only one or no parasitic elements may be used in order to decrease fabication cost and complexity at the expense of decreased gain toward the horizon).

As mentioned previously, antenna 50 as described has relatively broadband characteristics and thus can be operated over a relatively wide operating frequency range with acceptable impedance matching. However, it is often desirable in mobile radio applications to operate antenna structure 50 over a very broad range of operating frequencies (e.g., 820 MHz to 890 MHz) with acceptable VSWR (2.0 to 1 or less) over that entire range. To achieve this wide bandwidth, antenna structure 50 can be modified to include a microstrip line-type impedance matching network 150 of the type shown in FIGURES 9 and 10.

Matching network 150 includes microstrip line 152 disposed on a strip of insulative material 154, that insulative strip being disposed on disk upper surface 64. As shown in FIGURE 10, coaxial cable center conductor 156 may be connected directly to microstrip line 152 using a conventional solder joint 158 or the like. Holes 160 and 162 may be drilled through disk 62 and insulative strip 154, respectively, to permit center conductor 156 to pass through the disk to microstrip line 152 without electrically contacting the disk. The capacitive reactance between microstrip line 152 and disk 62 in conjunction with the inductive reactance introduced by coaxial cable center conductor 156 (or, alternatively, the feed-through pin of a conventional RF connector used to feed antenna structure 50) provides a resonant circuit, resulting in a broadband impedance match.

FIGURES 11-13 schematically show the RF radiation pattern of antenna structure 50 shown in FIGURE 3 as installed within roof structure 52 of automobile 54. FIGURE 11 graphically illustrates the vertically-polarized omnidirectional radiation pattern of antenna structure 50 in the x-y plane (plane of the horizon when disk 62 is oriented in that plane) and also the relatively low angle of radation in the z direction attributable in part to the effect of parasitic element 58 (this low angle of radiation is also graphically shown in FIGURE 12). FIGURE 13 is a Smith chart showing two plots The actual measured radiation pattern (field stength measurements) of antenna structure 50 shown in FIGURE 3 as mounted within roof structure 52 (this plot is labeled "A"); and the plot of a trunk mounted quarter wavelength whip antenna (of the type shown in FIGURE 1) mounted on the same vehicle (this plot is labeled "B").

FIGURE 14 is a Smith chart showing results of input impedance measurements for the antenna structure 50 shown in FIGURES 7 and 8. This chart demonstrates that a VSWR (voltage standing wave ratio) less than 2.0 to 1 over the range of 820 MHz to 890 MHz can be obtained.

FIGURE 15 shows a further embodiment of antenna structure 50 having a discoid conductive reference surface 60 which has substantially the same size and shape as circular radiator element 56. This embodiment, which is attractive because of its symmetry, may be useful in applications where RF shielding below reference surface 60 is not required.

A new and advantageous antenna structure has been described which has a omni-directional RF

radiation pattern, is inexpensiv and easy to produce in large quantities, and can be constructed in a low profile packag . Th antenna structure is conformal (that is, it may lie substantially within the same plan as its supporting structure), and because of this and its small size, may be incorporated into the roof structur of a passenger vehicle. Th disclosed antenna structure is ideally suited for use as a passenger automobile mobile radio UHF ant nna becaus of these characteristics.

While the present invention has been described with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the appended claims are not to be limited to the disclosed embodiments, but on the contrary, are intended to cover all modifications, variations and/or equivalent arrangements which retain any of the novel features and advantages of this invention.

Claims

1. A radio frequency antenna for vehicular installation, said antenna comprising:

a conductive reference surface;

a circularly shaped conductive radiator element of at least one-half wavelength in diameter disposed above said reference surface by substantially less than one-fourth wavelength and electrically shorted to said reference surface near the center of the circularly shaped element to form a shorted one-fourth wavelength radius annular cavity having a first circular radiating slot at its outer edge;

an RF signal feed connection located between the reference surface and a predetermined matched impedance point on said circular radiator element; and

at least one further annular conductive radiator element spaced radially outwardly from said first circular radiating slot and also disposed above said reference surface by substantially less than one-fourth wavelength, said further radiator element also having a resonant radial dimension to form at least on further circular radiating slot at one of its edges.

2. A radio frequency antenna as in claim 1 wherein said further annular conductive radiator element has a radial dimension of substantially one-fourth wavelength and has its inner radius shorted to said reference surface to form an annular shorted one-fourth wavelength radius circular radiating slot at its outer edge.

3. A radio frequency antenna as in claim 1 wherein said second radiating slot is located about 0.2 to 0.4 wavelength radially outwardly of said first radiating slot.

4. A radio frequency antenna as in claim 1 wherein said further annular conductive radiator element comprises a passive parasitic director having no directly connected RF feedpoint but providing increased antenna gain at the horizon when said radiator elements and conductive reference surface are horizontally disposed.

5. A radio frequency antenna as in claim 1, 2, 3 or 4 comprising a plurality of said further annular conductive radiator elements, each successive additional such further element being located radially outwardly of the just preceding one.

6. A radio frequency antenna as in claim 1 installed in the roof of a vehicle with the conductive reference surface disposed over a passenger section of the vehicle.

7. A radio frequency antenna as in claim 1 wherein said RF signal feed connection includes a predetermined length of microstrip transmission line disposed on said radiator element and connected to resonate with other feed connection components so as to provide a substantially matched RF impedance over a broadened band of frequencies.

8. A radio frequency antenna as in claim 1 having an operational bandwidth including 825 MHz to 890 MHz.

9. A radio frequency antenna as in claim 1 wherein said conductive elements comprise die-formed aluminum structures.

10. A low profile UHF radio frequency antenna structure comprising:

a first part comprising a conductive material, said first part having a circular periphery and first and second opposing surfaces, said first part also having a depression in substantially the center of said first surface and a cylindrical, hollow portion protruding from said second surface, said depression communicating with the hollow within said protruding portion, said protruding portion having a distal terminus;

a second part comprising a conductive material, said second part having a substantially cylindrical depression surrounded by an outwardly extending flange, said cylindrical depression having a bottom portion;

means for m chanically and electrically attaching said first part protruding portion terminus to said

second part bottom portion; and

an RF feedline connected betw en said second part and a predetermined impedance matching point on said first part.

11. An antenna structure as in claim 10 wherein said flange is annular.

12. An antenna structure as in claim 10 wherein said flange has a width which is approximately half the diameter of the circular periphery of said first part.

13. An antenna structure as in claim 10 wherein the bottom of said second part cylindrical depression is circular and has a diameter which is substantially larger than the diameter of said first part.

14. An antenna structure as in claim 10 wherein an annular gap is defined between said first part periphery and said flange.

15. An antenna structure as in claim 10 wherein said first part first surface and said flange are coplanar.

16. An antenna structure as in claim 10 wherein said attaching means includes:

structure extending from said terminus; and

at least one aperture defined through said bottom portion into which said structure is inserted.

17. An antenna structure as in claim 10 further including a sheet of conductive material coupled to said second part bottom portion.

18. An antenna structure as in claim 10 wherein said protruding portion is frustoconical where it joins said second surface.

19. An antenna structure as in claim 10 wherein said protruding portion includes a frustoconical portion and a cylindrical portion joined thereto, said cylindrical portion terminating in said terminus, said frustoconical portion being connected to the remainder of said first part.

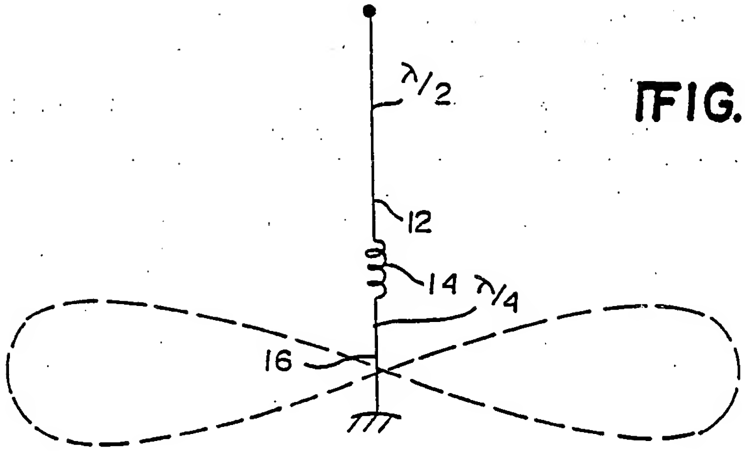


FIG. 1 PRIOR ART

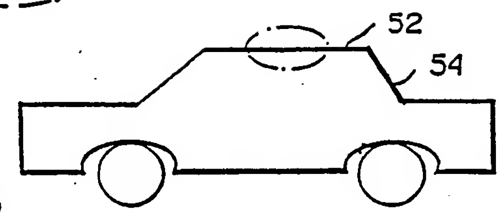


FIG. 2

FIG. 3

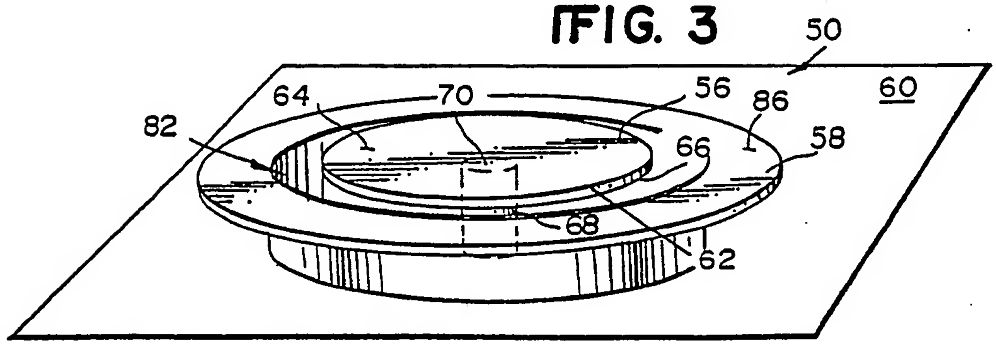
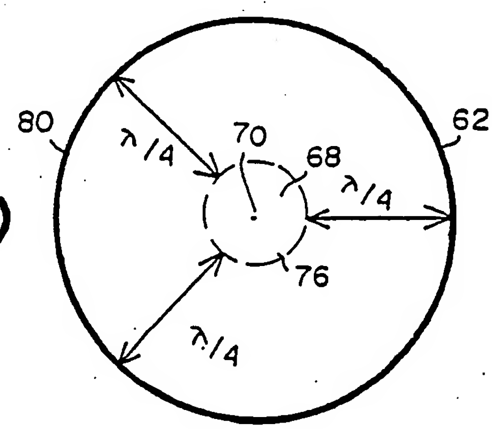
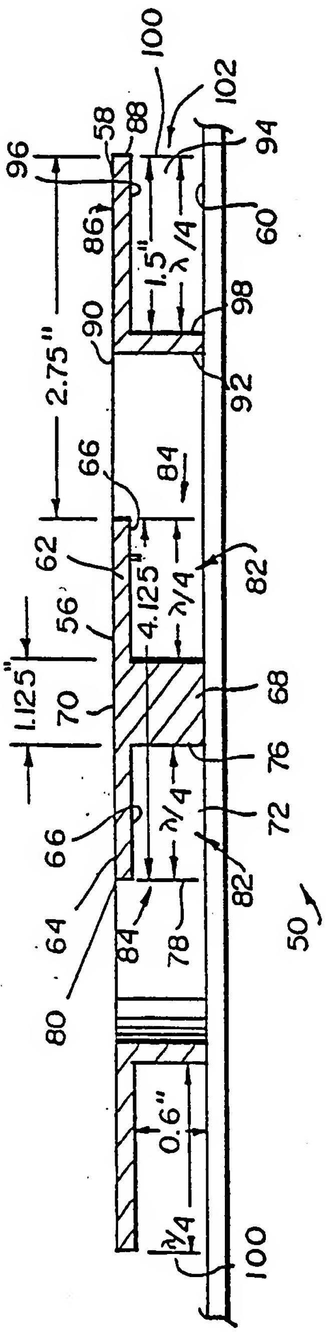


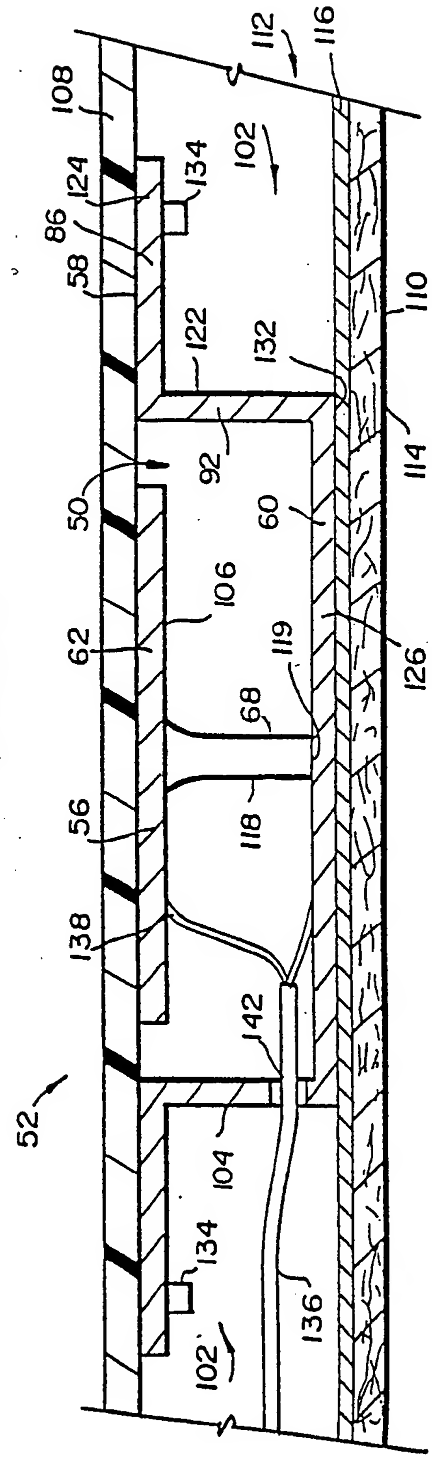
FIG. 4 (A)





96
58
88
100
102
94
86
60
1.5"
λ/4
2.75"
90
98
92
66
84
62
4.125"
82
56
1.125"
70
68
76
λ/4
72
64
78
80
0.6"
λ/4
100
50

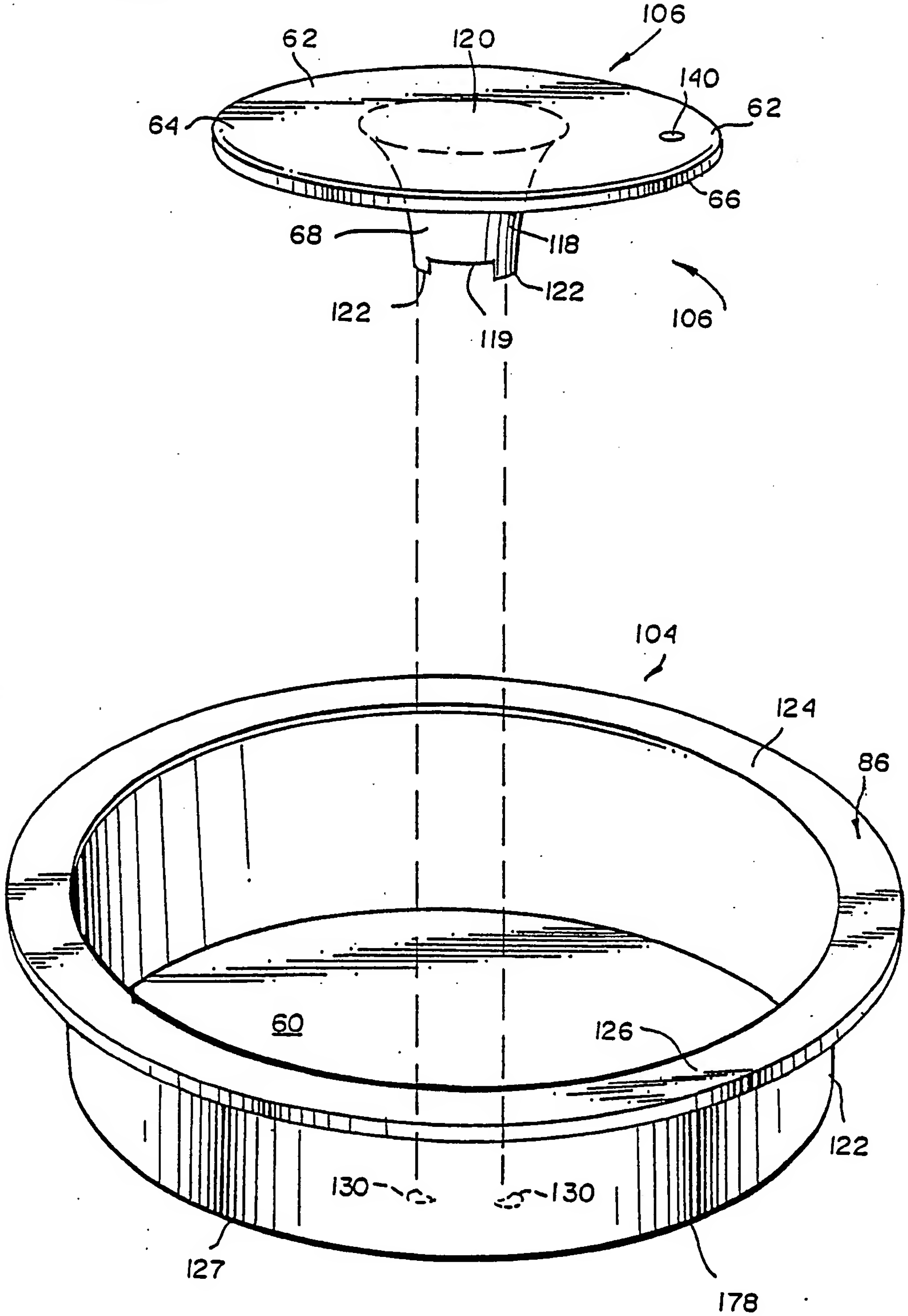
FIG. 4



108
112
116
124
134
102
86
58
110
122
132
114
50
92
60
106
62
119
126
68
56
118
138
142
52
104
134
136
102

FIG. 5

FIG. 6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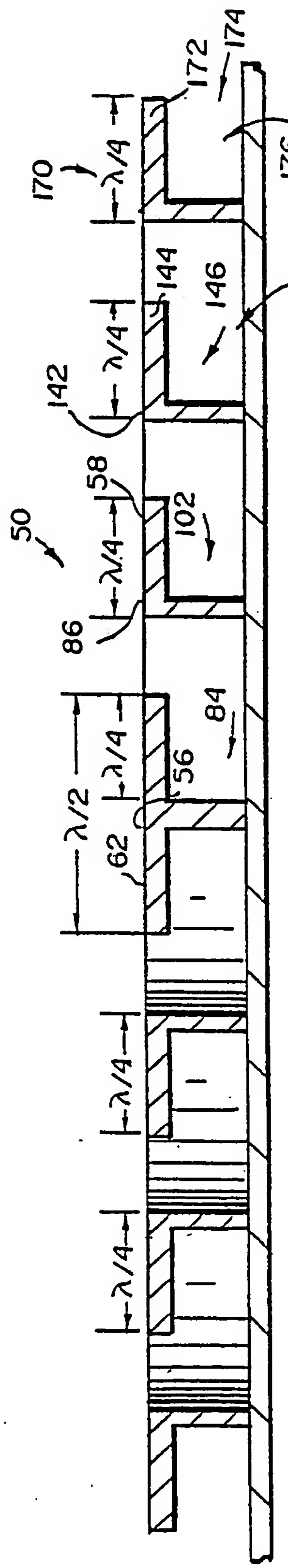
62
120
140
62
64
66
68
118
122
122
119
106
104
124
86
60
126
122
130
130
127
178


50
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172
174
176
144
146
148
142
58
102
86
84
56
62
λ/4
λ/4
λ/4
λ/2
λ/4
λ/4
λ/4

FIG. 7

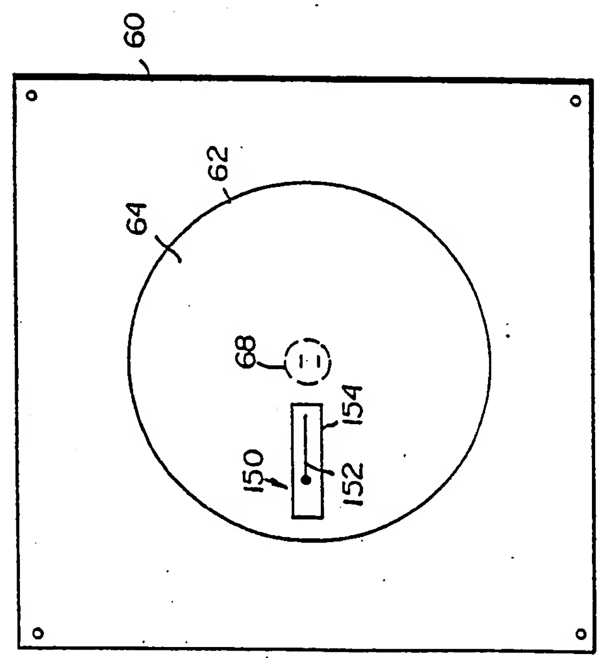

60
62
64
68
150
152
154

FIG. 9

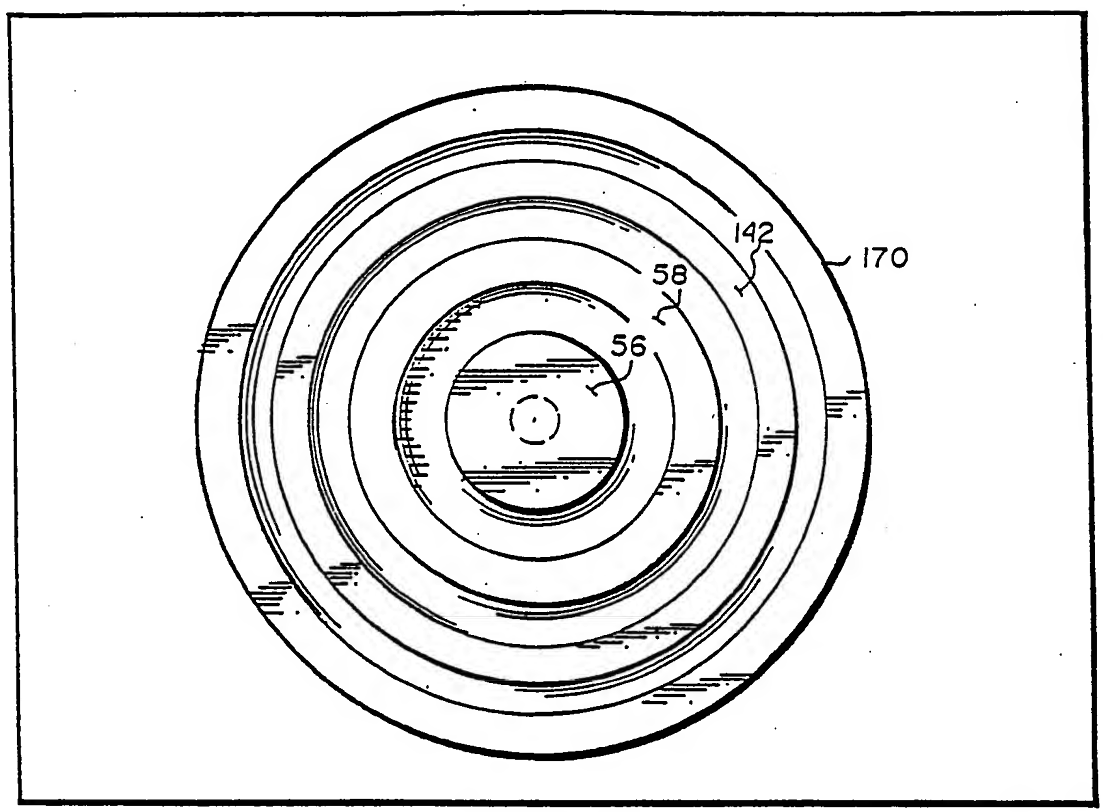
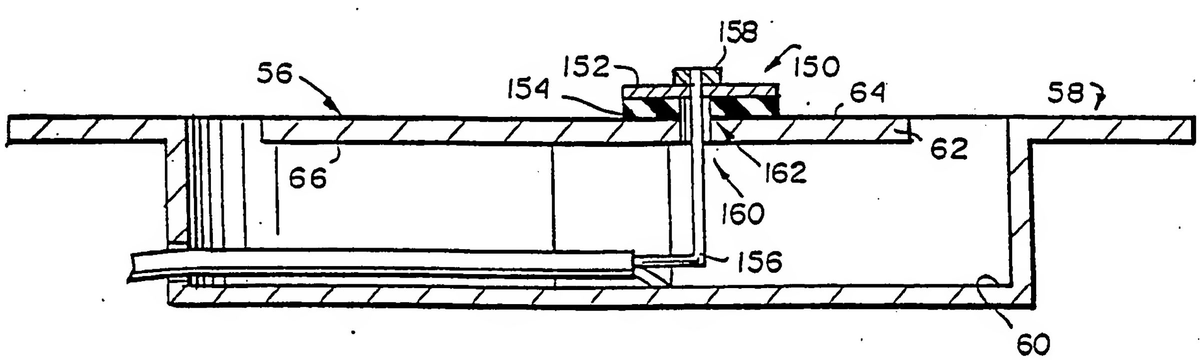


FIG. 8

FIG. 10



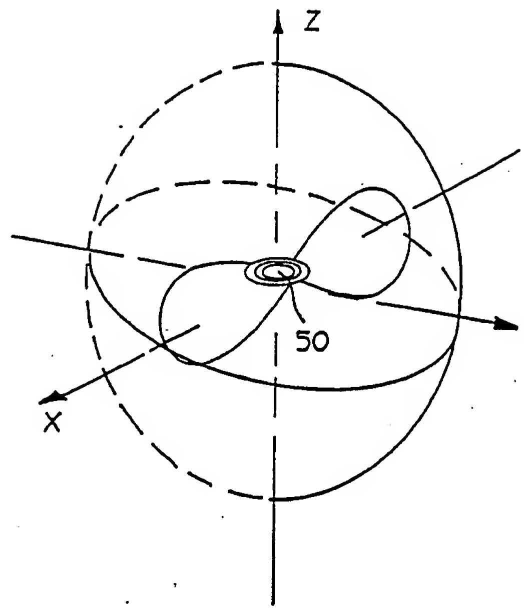
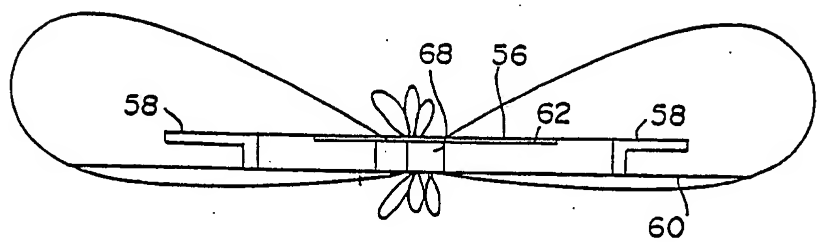


FIG. 11

FIG. 12



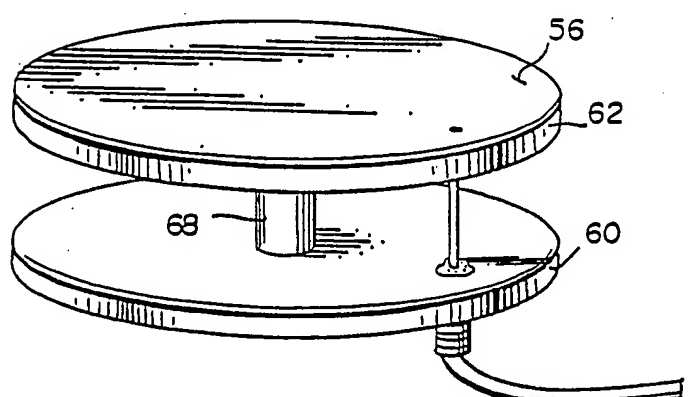


FIG. 15

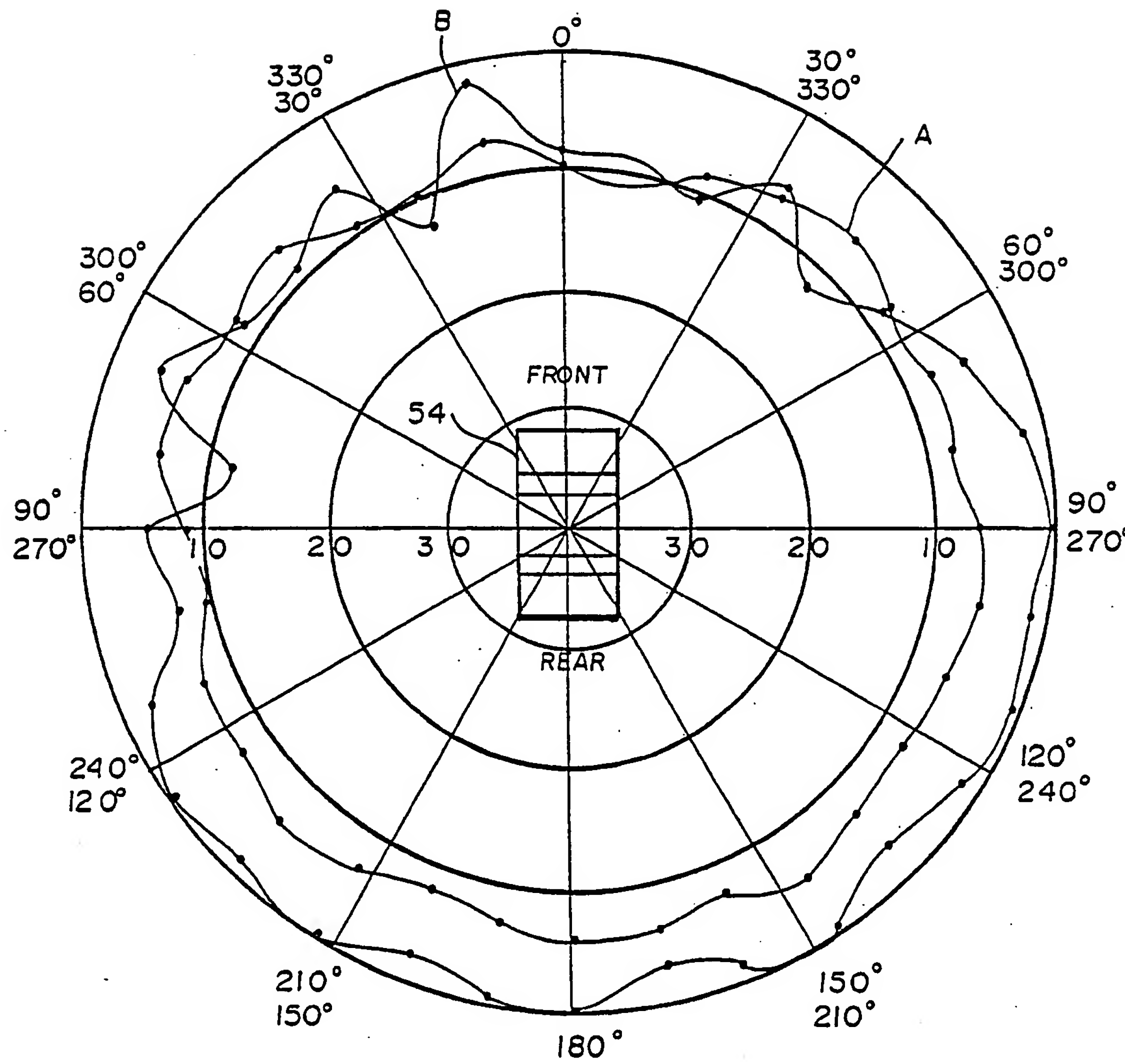

B
0°
330°
30°
30°
330°
A
300°
60°
60°
300°
FRONT
54
90°
270°
1 0
2 0
3 0
3 0
2 0
1 0
90°
270°
REAR
240°
120°
120°
240°
210°
150°
150°
210°
180°

FIG. 13

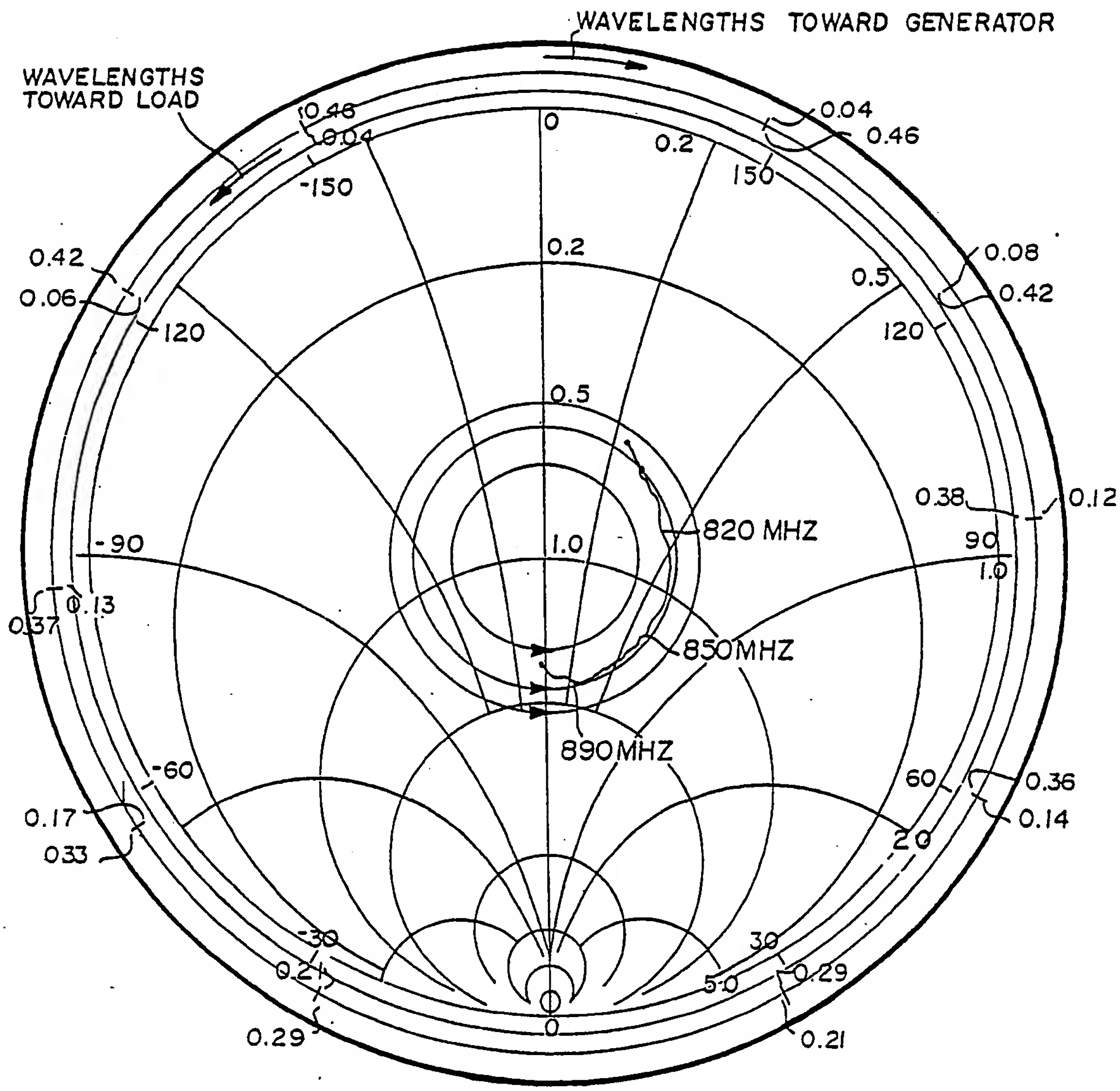

WAVELENGTHS TOWARD GENERATOR
WAVELENGTHS TOWARD LOAD
0.46
0.04
-150
0
0.2
150
0.04
0.46
0.42
0.06
120
0.2
0.5
120
0.08
0.42
0.5
820 MHZ
0.38
0.12
-90
1.0
90
1.0
0.13
0.37
850MHZ
890MHZ
-60
60
0.36
0.14
0.17
0.33
2.0
-30
30
0.21
5.0
0.29
0.29
0
0.21

FIG. 14

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 87 11 6865

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	IEEE TRANSACTIONS ON ATENNAS AND PROPAGATION AP33, 1985, pages 655-659, no. 6, New-York, US; A.K. BHATTACHARRYYA et al.: "A microstrip array of concentric annular rings" * page 655, figure 1 *	1,10	H 01 Q 9/04 H 01 Q 1/32
A	IDEM	4,5	
D,Y	US-A-2 996 713 (J.M. BOYER) * figure 3; column 2, lines 32-60 *	1,10	
D,A	* figure 1; column 2, line 35 *	6	
A	US-A-2 508 085 (A. ALFORD) * figure 2; column 3, lines 10-46 *		
A	US-A-4 401 988 (C.M. KALOI) * figure 2; column 1, lines 49-54 *		
A	PATENT ABSTRACT OF JAPAN, vol. 9, no. 69 (E-305)[1792], 29th March 1985; & JP - A - 59 207 705 (NIPPON DENSO) 24-11-1984		

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

H 01 Q 1/32
H 01 Q 9/04
H 01 Q 13/18

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	27-04-1988	BREUSING J

CATEGORY OF CITED DOCUMENTS

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